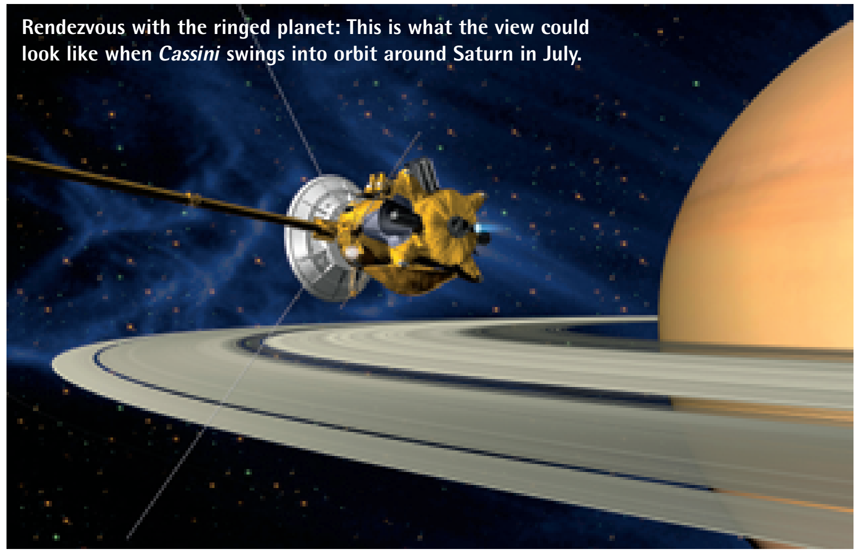
Visiting the Lord of the Rings

When Cassini *swings into orbit around Saturn on July 1, a journey of almost eight years will have come to an end. A cosmic game of billiards in the gravitational fields of Venus, Earth and Jupiter has catapulted the probe toward its destination. The spacecraft will orbit the giant planet for a minimum of four years, investigating its world of rings and moons. And in January 2005, the landing probe* Huygens *will touch down on the surface of its moon Titan. The Max Planck Society is participating in this ambitious mission with four instruments, which have already provided valuable data during the satellite's outward-bound journey.* **NORBERT KRUPP** *from the* **MAX PLANCK INSTITUTE FOR AERONOMY** *in Katlenburg-Lindau reports about the mission and the devices.*



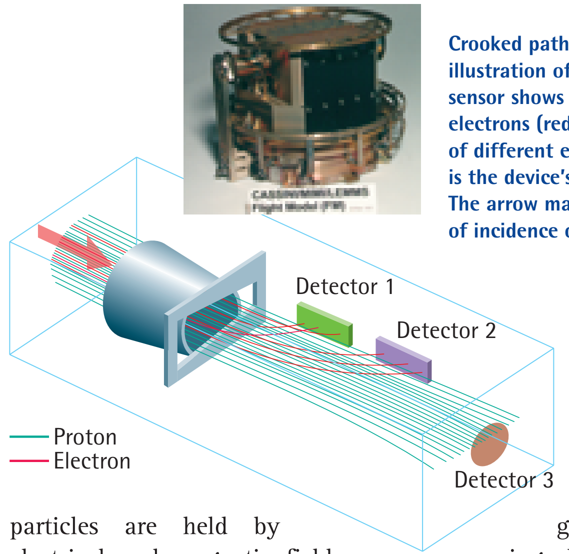
Rendezvous with the ringed planet: This is what the view could look like when *Cassini* swings into orbit around Saturn in July.

The space probe *Cassini* took off into space from Cape Canaveral in October 1997 – the beginning of one of the most exciting journeys ever to be undertaken to a planet in our solar system. Also involved in the NASA mission are the European Space Agency (ESA) and the Italian space agency (ASI). *Cassini* houses 12 scientific instruments, while a further 6 are located on the landing probe *Huygens*.

The Max Planck Institute for Aeronomy in Katlenburg-Lindau contributed crucial components for *Cassini*'s particle spectrometer MIMI/LEMMS and its ultra-violet spectrometer UVIS/HDAC, as well as for the DISR camera system on board *Huygens*. In addition, the Max Planck Institute for Nuclear Physics in Heidelberg took on the job of constructing *Cassini*'s dust detector, CDA. The mission was named after French astronomer Giovanni Domenico Cassini (1625 to 1712) and his Dutch colleague Christiaan Huygens (1629 to 1695).

The highlight of the mission to date has been the flyby at Jupiter in December 2000 and January 2001. The results have already proven just what an outstanding job the scientists, engineers and technicians at all levels have done, as the data is truly unique. It was collected, for example, by the Magnetospheric Imaging Instrument MIMI, which is composed of three sensors: MIMI/INCA (the Ion Neutral Camera), MIMI/CHEMS (the Charge Energy Mass Spectrometer) and MIMI/LEMMS (the Low Energy Magnetospheric Measurement System). MIMI measures the charge states, energy and flight directions of atoms and charged particles. The device enables us to visualize the usually invisible magnetosphere – a type of magnetic protection shield around planets.

Fascinating processes occur in this type of natural "laboratory." While neutral particles can leave their formation point unhindered, charged particles are held by electrical and magnetic fields, enabling the direction and strength of such fields to be ascertained. The device allows the movements of particles to be determined and the global configuration of magnetic fields and particle dynamics to be analyzed.



Crooked paths: The schematic illustration of the MIMI/LEMMS sensor shows the path of electrons (red) and ions (green) of different energies. Above is the device's flight unit. The arrow marks the angle of incidence of particles.

ILLUSTRATION: ROHRER

Planets other than the Earth – for example Saturn and Jupiter – also possess an internal magnetic field and, by association, a magnetosphere. A magnetosphere forms a boundary between a planet (and its close vicinity) and the surrounding solar wind, partially protecting it against the latter. Without its magnetosphere, life would not be possible on Earth. Magnetospheres are the largest objects in our solar system. If it were visible from Earth, Saturn's magnetosphere would have a diameter almost two times larger than the diameter of the Sun; Jupiter's would even be ten times as large. We hope that MIMI will give us a better idea how this protective shield works and what physical processes occur within planetary magnetospheres – particularly in Saturn's.

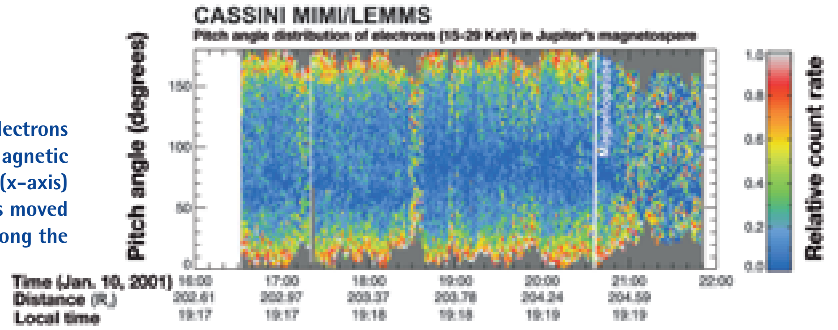
The diagram above illustrates how measurements are taken using the instrument developed by the Max Planck Institute for Aeronomy and sponsored by the German Aerospace Center (DLR). The red and green lines depict incoming electrons and ions, which enter the instrument via a funnel-like aperture (arrow). A honeycomb-like structure very precisely defines the direction of the incoming particles. Owing to the Lorentz force, ions and electrons of varying mass and charge are registered by semiconductor detectors at various locations inside the instrument. A magnet bends the path of the electrons and sends them to detectors 1 and 2, while positive ions are much more weakly deflected in the opposite direction (due to their higher mass and positive charge, respectively) and arrive at detector 3. This allows us to detect ions and electrons of different energies. The instrument is mounted on a rotating platform, enabling us to also measure the incident direction of the particles.

The results from MIMI/LEMMS during *Cassini*'s Jupiter flyby showed that the Jupiter magnetic field lines still close at a distance of 200 planetary radii (14 million kilometers) and are bound to the planet (figure below). This was concluded from measurements of "pitch angle distribution," in which the incidence angles of incoming particles relative to the direction of the magnetic field was recorded. Most electrons within Jupiter's magnetosphere travel along its magnetic field lines to and from the north and south poles (pitch angles of 0 and 180 degrees).

MIMI's early successes have greatly raised expectations for Saturn. We hope to take the first direct measurements of highly energetic neutral particles (ENAs) from the planet and its moon Titan. In addition, we will be able to take extremely detailed, global measurements of the distribution of electrons and ions in Saturn's magnetosphere – and, for the first time, measure the charge states of these ions.

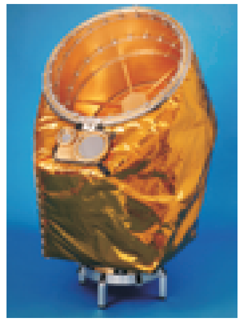
A LOOK AT THE HISTORY OF THE SOLAR SYSTEM

Cassini also has a further instrument on board, the Ultraviolet Imaging Spectrograph UVIS (figure on page 48). It is composed of several detectors, each sensitive to a particular range of wavelengths. One of these, the Hydrogen-Deuterium Absorption Cell (UVIS/HDAC), developed by the Max Planck Institute for Aeronomy, should, for the first time, directly determine the ratio of deuterium (D) – the heavier isotope of hydrogen – to hydrogen (H) in the atmosphere of Saturn's moon Titan. The present D/H ratios for Titan's atmosphere were established using infrared measurements from the ground and from Earth orbit, in which spectral lines from hydrogen-

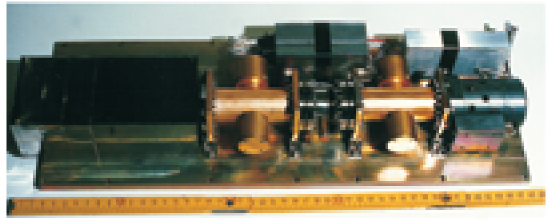


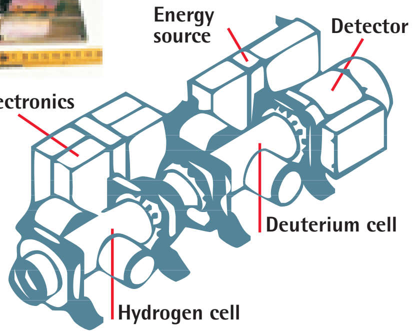
Fingerprints of the magnetic field: The relative number of electrons is shown in color as a function of the angle relative to the magnetic field (y-axis) and as a function of the distance from Jupiter (x-axis) recorded using the MIMI/LEMMS sensor. Most electrons moved either at 0 or at 180 degrees to the magnetic field (along the magnetic field lines) when the space probe was inside Jupiter's magnetosphere. Once Cassini crossed the magnetopause, the field lines lost their connection to Jupiter.

ALL FIGURES: MPI FOR AERONOMY



Precious piece: The *Cosmic Dust Analyzer* (CDA) packed in thermal insulation foil. The circular detector housing has a diameter of 40 centimeters. Inside the aperture, the gratings and the struts of the multiplier housing can be seen. The device also contains a turntable to rotate it into the direction of the dust flow.





High-tech on board: Flight unit and schematic illustration of the Hydrogen-Deuterium Absorption Cell UVIS/HDAC, built to measure the ratio of deuterium to hydrogen in the atmosphere of Saturn's moon Titan.

Illustration: Rohrer

containing molecules, such as methane (CH$_4$ and CH$_3$D), were measured. The D/H ratio could then be estimated using assumptions arising from models of the chemical behavior of deuterium and hydrogen. Processes involved in the birth and development of the solar system have influenced the D/H ratios in planetary atmospheres. Measuring this ratio will therefore give us a chance to find out more about the history of our planetary system. The *Cassini* mission offers us a particularly good opportunity to do just this, as Saturn's largest moon Titan (the second largest in the solar system) is the only large orbiting body in the solar system with a significant atmosphere. By comparing the D/H ratios in Saturn and Titan, new information can be acquired about the formation and development of not only Saturn, but also the entire solar system.

HDAC will determine the D/H ratio by observing solar Lyman-alpha radiation scattered in Titan's atmosphere. As the Lyman-alpha lines of both isotopes are only marginally different from one another (hydrogen 1,215.67 angstroms, deuterium 1,215.34 angstroms), a conventional spectroscope capable of being installed on a spacecraft would be incapable of providing the required resolution to separate them. Instead, *Cassini* will provide this measurement directly from the Hydrogen Deuterium Absorption Cell, HDAC. This instrument is constructed of cells ordered along the axis of the instrument containing either molecular hydrogen (H$_2$) or deuterium (D$_2$). Incoming light crosses the cells and is registered by a photodetector. Heat generated by tungsten filaments located in the two cells splits many of the H$_2$ and D$_2$ molecules into their separate atoms. These atoms then absorb a part of the incoming Lyman-alpha radiation and, as a consequence, lower the detector's count rate.

The heat output of the tungsten filaments can be used to control the concentration of H or D atoms in the cells, and therefore their absorbing capacity. This allows a large portion of the Lyman-alpha radiation scattered by atomic hydrogen in Titan's atmosphere to be absorbed – and makes it possible to measure the significantly weaker deuterium signal. A suitable combination of absorbing capacities in both cells can be used to determine the D/H ratio. The most important measurements taken by this instrument are planned for the Titan flyby on December 26, 2005. During this event, *Cassini*'s radial velocity in relation to Titan will alter radically. The resulting Doppler effect on the spectral lines should allow us to precisely measure the configuration of the hydrogen lines, increasing the degree of accuracy with which the D/H ratio can be measured.

The Max Planck Institute for Nuclear Physics is responsible for the German Cosmic Dust Analyzer (CDA). This sensor can detect the presence of two types of dust: interplanetary, stemming from comets or asteroids, and interstellar, which "blows through" our solar system, but whose origin lies outside of it. It can detect particles with a velocity of 5 kilometers per second and a mass of 10-16 kilograms (equivalent to two-thousandths of a millimeter in size). In addition to the velocity and size of particles, it can also determine the electrical charge and the elemental composition of dust particles. The CDA experiment has been successfully operating in interplanetary space since 1999 and is continually sending valuable data back to Earth, providing the "dust scientists" with a great number of new findings and results.

Dust-Catcher in Interplanetary Space

The time-of-flight mass spectrometer in the instrument determines the elemental composition of the micrometer-sized dust particles. During the Jupiter flyby, the time frame for registering dust rates was limited to 12 hours, but high impact rates were recorded in this period. Together with the measurements taken simultaneously using the dust detectors on board the *Galileo* space probe, it was possible to ascertain the phase shift of both rates using correlation analysis. The results show that dust "blows" at a velocity of 400 kilometers per second, and that the particles have a radius of just 8 nanometers.

Such successful results are generating high expectations for the future. Saturn is known for its ring system composed of dust and rocky debris. Dust particles range in size from a thousandth of a millimeter (E ring) to the size of an apartment building (inner rings). Rings lying adjacent to and outside the optically thick inner rings (designated A to D) are known to exist. Of these, the E ring is of special interest, extending between three and eight Saturn radii. As *Cassini* is scheduled to fly frequently through this ring, its micrometer-sized dust particles can be directly detected. *Cassini*'s dust detector certainly won't answer all of our questions, but its results will bring us a good deal closer to a few answers.

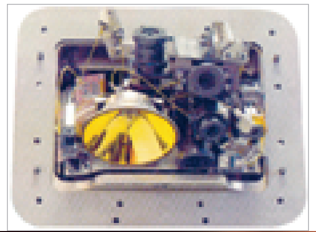
Without a doubt, one of the highlights of the mission will be the arrival of the atmospheric and landing probe *Huygens* on Titan. The prevailing surface pressure is equal to one and a half Earth atmospheres, and its atmosphere is primarily composed of nitrogen. However, it possesses no oxygen, instead containing methane and, possibly, the noble gas argon. Ultraviolet light from the Sun splits the nitrogen and methane molecules in Titan's stratosphere, creating complex organic compounds.

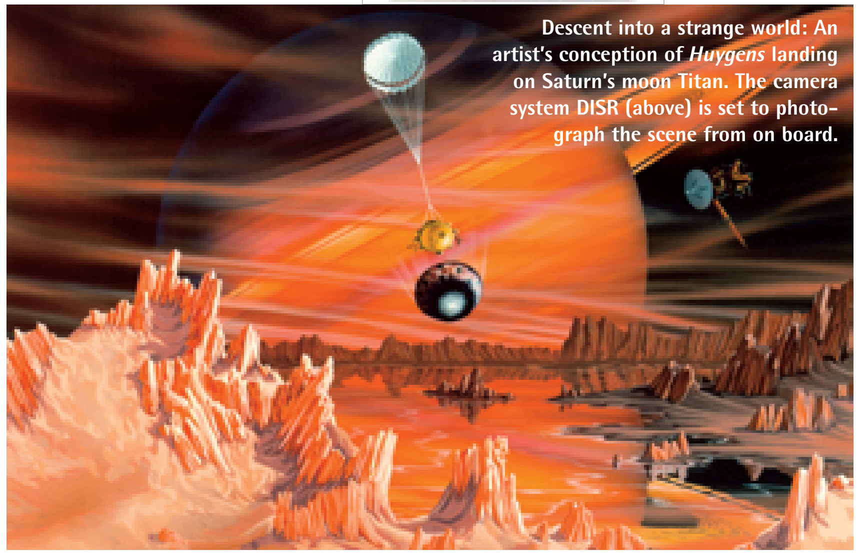
Despite the much colder surface temperature of minus 180 degrees Celsius, chemical processes on Titan are similar to those on the young Earth, which eventually led to life's origin. The organic compounds agglomerate into aerosols, forming the hazy orange-colored layer in which Titan is veiled. During the *Voyager 1* flyby in 1980, it was this haze that hid the surface from the spacecraft's optical-wavelength cameras. Titan's atmosphere is more transparent toward the infrared portion of its spectrum and, utilizing this, scientists employing the *Hubble* space telescope, as well as a number of Earth-bound telescopes, have been able to work out some surface details – including a relatively bright area about the size of Australia. The causes of such observable differences in brightness are still unclear.

The European probe *Huygens* should land on Titan on January 15, 2005. The Max Planck Institute for Aeronomy is involved with one of the scientific instruments on board, the Descent Imager/Spectral Radiometer. The DISR is composed of a complicated combination of several cameras and spectrometers that are set to take photographs and measure radiation at different angles and wavelengths during the probe's two-and-a-half-hour descent by parachute. Light will be detected from a total of 10 optical devices via glass fibers to jointly used sensors: photodiodes for ultraviolet and infrared light, and an electronic camera (CCD) for the visible spectrum. Data will be relayed during the ascent to the *Cassini* mothership, stored, and finally, broadcast back to Earth.

The upwardly directed DISR's radiation measurements are designed to study the atmosphere. The appearance of the Sun's aureole and the spectrum and polarization of its radiation will be able to tell us about the composition of the atmosphere and the nature of the aerosols in the haze layer. Spectrometers directed downwards will enable us to analyze the material on the surface, which is thought to be largely composed of water ice and to be covered by an organic sludge that has trickled down from the skies above. The DISR's cameras are set at various angles.

The main emphasis of the *Huygens* mission will be to take measurements during descent. However, if the probe does land safely after its parachute-slowed surface impact, it should carry on collecting data. In the event of a splash-landing into a sea of methane, there should be no problems either – the probe can float ...





Descent into a strange world: An artist's conception of *Huygens* landing on Saturn's moon Titan. The camera system DISR (above) is set to photograph the scene from on board.

This essay was written in collaboration with Ralf Srama (Max Planck Institute for Nuclear Physics in Heidelberg), Björn Grieger and Stefan Werner (Max Planck Institute for Aeronomy).

Dr. Nobert Krupp (born in 1963) studied physics at the University of Kaiserslautern and received his doctorate at the Institute for Geophysics and Meteorology at Braunschweig Technical University, in cooperation with the Max Planck Institute for Aeronomy in Katlenburg-Lindau. After a postdoc residence in the Applied Physics Laboratory at Johns Hopkins University in Laurel, Maryland (USA), he returned to become an active scientist at the Institute in Lindau. His main interest lies in the analysis of scientific information from space probes, and particularly data from Jupiter's and Saturn's magnetospheres. He is also involved in ground-based observations of the Sun's photosphere and chromosphere. Norbert Krupp is the "principal investigator" of the EPAC particle detector on board the *Ulysses* space probe, and "co-investigator" of both the MIMI and UVIS instruments on board *Cassini*, and ASPERA on *Mars Express*. He is also responsible for public relations at the Institute.